(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) Publication number: **0 582 715 A1**

(12) **EUROPEAN PATENT APPLICATION published in accordance with Art. 158(3) EPC**

(21) Application number: **93901525.1**

(22) Date of filing: **18.01.93**

(86) International application number: **PCT/JP93/00055**

(87) International publication number: **WO 93/14910 (05.08.93 93/19)**

(51) Int. Cl.5: **B25J 19/06**

(30) Priority: **28.01.92 JP 35816/92**

(43) Date of publication of application: **16.02.94 Bulletin 94/07**

(84) Designated Contracting States: **DE IT SE**

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(54) **METHOD OF CONTROLLING A PLURALITY OF ROBOTS.**

(57) A plurality of robots (A, B) that are installed adjacent to one another may be instructed to simultaneously operate, space areas occupied by the robots having respective positions and postures in accordance with respective operation commands are defined by one or two planes (Pa1, Pa2; Pb1, Pb2). Such planes for all the robots are parallel (to XZ plane) and have translational motion in a predetermined direction (Y-axis direction), and it is determined whether or not the space area thus defined crosses the space area defined for another. When the defined space areas for the two robots are apart, the robot (A) operates in accordance with the operation command, assuming that interference between the robots does not occur. On the other hand, when an overlap between the defined space areas for the two robots are detected, the robot (A) is stopped and kept on stand-by until the two space areas become apart as a result of the progress of the operation of the other robot (B).

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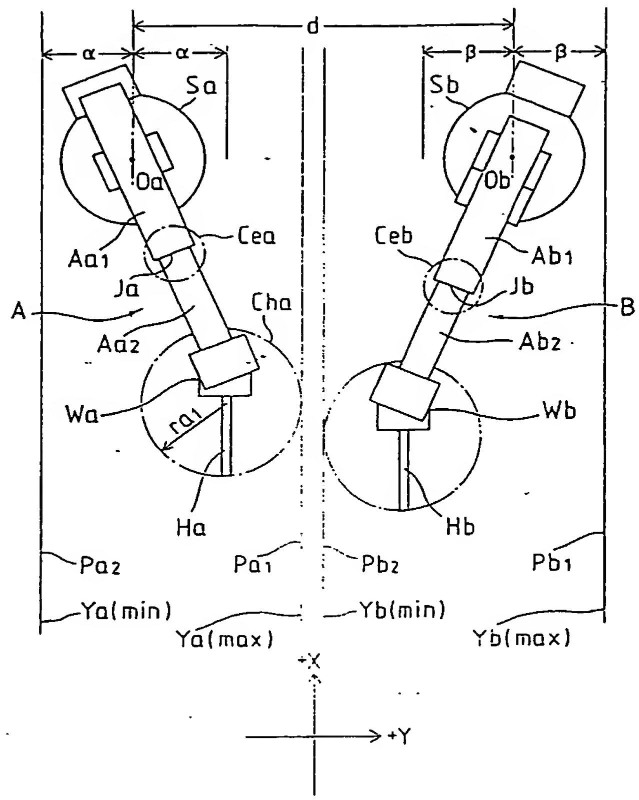
FIG. 1


d
α
α
β
β
Sa
Sb
Oa
Ob
Cea
Ceb
Aa1
Ab1
Ja
Jb
A
B
Cha
Aa2
Ab2
Wa
Wb
ra1
Ha
Hb
Pa2
Pa1
Pb2
Pb1
Ya(min)
Ya(max)
Yb(min)
Yb(max)
+X
+Y

Technical Field

The present invention relates to a multiple-robot control method, wherein a plurality of robots mounted close to each other are controlled so that there is no interference with each other between these adjacent robots when these robots are simultaneously operated according to a command.

Background Art

If a plurality of robots mounted close to each other execute a task in cooperation with each other, operation efficiency can be improved; on the other hand, care must be taken so that there is no interference between these robots. For this reason, there is a conventional control method of predicting a region where there is the possibility of causing interference between robots, and of letting one robot wait so as not to enter the region for the duration when the other robot exists in the region and is operating therein, in order to prevent two robots from being simultaneously operated in the same region by taking advantage of communication between robots.

However, it is not easy to predict the aforementioned region where the robots interfere with each other. If the region is broadly set in consideration of sufficient margin such that these robots have no interference with each other, the time during which one robot of them exists in the aforesaid region set thus becomes long. As the result, a waiting time of the other robot also becomes long; for this reason, the operating efficiency lowers. On the other hand, if the minimum region where the robots have no interference with each other is predicted and preset to enhance the operating efficiency, it is necessary to make a complicated computation for the prediction. Therefore, accurate prediction is difficult to make. Further, it is considerably hard to preset the timing of communication between the robots; for this reason, there is the disadvantage that the number of processes increases in order to effectively operate the plurality of robots so as not to cause interference in the predicted region.

Disclosure of the Invention

An object of the present invention is to provide a multiple-robot control method, wherein there is no need of predicting a region where the plurality of robots interfere with each other, operation programs is freely taught to each robot, and no interference occurs during the operation of the robots.

To achieve the above object, the present invention provides a multiple-robot control method, comprising the steps of: defining a spatial region for keeping a region necessary to the operation every unit operation command for each of a plurality of, for example, vertically jointed type robots which are mounted close to each other, and commanded so as to be operated at the same time, finding whether the aforesaid defined spatial region crosses a spatial region which is defined and kept for other robot likewise, and determining whether it is ensured that no interference between robots occur.

Further, the present invention provides a multiple robot control method, comprising the steps of: finding that the spatial region, which is defined and kept for one robot, cross the spatial region which is defined and kept relative to the other robot, and controlling so that the aforesaid one robot is stopped operating according to the detected result, and is kept in a waiting state until the spatial region of one robot moves depending on an operation of the aforesaid other robot, and the spatial regions of both robots do not cross each other.

Preferably, the occupied spatial region of the aforesaid each robot is defined by one or two planes, which are parallel to each other and horizontally moves in a specified direction.

More preferably, the aforesaid plane for defining the spatial region of each robot is set to a position such that the plane is tangential to the sphere or cylinder obtained by assuming at least one of a sphere covering a wrist and hand of the robot, a sphere covering an elbow joint of the robot, and a cylinder representing a base of the robot, and receives it within the region defined by the plane. Further, the plane is set to a position such that the plane is tangential to the sphere or cylinder detected as being positioned the furthest place from the robot base in the moving direction of the planes, of the at least two of spheres or cylinder which are assumed from among a sphere covering a wrist and a hand of the robot, a sphere covering an elbow joint of the robot, and a cylinder representing a base of the robot, and receives it within the region defined by the plane. In this case, the central position of the assumed sphere covering the wrist and the hand of the robot is set to a position where a predetermined offset value is added to the wrist center position, which is one of operating command positions. The radius of the sphere is determined on the basis of the structure of the wrist and the hand.

Furthermore preferably, the unit operation command for defining the spatial region of each robot is equivalent to one block of operating programs which is taught to the robot, or to data on which the operating command taught to the robot is interpolated.

Still more preferably, the spatial region closest to the adjacent robot of a spatial region newly

defined when the unit operation to each robot is started, and a spatial region defined just before the operation, is maintained as a spatial region for current operation until the next unit operation is started. Then, data on the maintained spatial region is transmitted to the adjacent robot. The robot receiving the data finds whether or not the spatial region crosses the aforesaid spatial region of the transmitting-side robot, and it is determined whether it is ensured that both robots have no interference with each other. If the receiving-side robot finds that the spatial region of the receiving-side robot crosses the aforesaid spatial region of the transmitting-side robot, the receiving-side robot is stopped operating, and is controlled so as to be kept in a waiting state until the spatial region of the receiving-side robot is moved depending on the operation of the transmitting-side robot, so that the spatial regions of both robots do not cross each other.

As described above, according to the present invention, the occupied spatial region of each robot can be readily defined every time when the operation command is given to each robot. Thus, the plurality of robots are controlled so that the opportunity, when one robot can execute one unit operation according to the operation command, is only when it is determined that the occupied region of one robot does not enter the occupied spatial region defined alike of tile other robot. Further, when the robot terminates one unit operation, the occupied spatial region of the aforesaid robot is defined and stored depending on the robot's position (orientation) at that time, thereby constituting a region inhibiting one robot from being entered the occupied spatial region of the other robot.

Brief Description of the Drawings

Fig. 1 is an explanatory view of one embodiment for carrying out a method according to the present invention;
Fig. 2 is a configuration diagram of a system controlling a plurality of robots by means of one robot controller;
Fig. 3 is a configuration diagram of a system controlling a plurality of robots by means of robot controllers connected by communication;
Fig. 4 is a block diagram showing main parts of the robot controller; and
Fig. 5 is a flowchart of robot control procedures according to one embodiment of the present invention.

Best Mode for Carrying Out the Invention

Fig. 1 is an explanatory view of one embodiment according to the present invention, and is a top plan view showing a state in which two robots A and B are mounted on a common plane through bases Sa and Sb. In the figure, Aa1 and Aa2 of a robot A denote arms, Ja denotes an elbow joint portion, Wa denotes a wrist, and Ha denotes a hand. Further, Ab1 and Ab2 of a robot B denote arms, Jb denotes an elbow joint portion, Wb denotes a wrist, and Hb denotes a hand.

The summary of the present embodiment is that a spatial region where the respective robots operate for every unit operation is set, and the aforesaid robots are controlled so that the respective spatial regions where these robots are operating do not cross each other, thereby preventing interference from occurring between these robots.

As shown in Fig. 1, a line connecting the centers Oa and Ob of the bases Sa and Sb is regarded as Y axis, and a line on the mounting plane and perpendicular to the Y axis direction is regarded as X- axis. Further, the direction perpendicular to the mounting plane (X-Y plane) is regarded as Z axis, thus X-Y-Z coordinate system being defined. The above spatial region for each robot is defined by one or two X-Z planes. In other words, each robot vertically stands depending on an orientation for unit operation, and occupies a spatial region defined by one or two plane shifting in the Y-axis direction in accordance with the operation of robot.

The spatial region is described below with reference to an example shown in Fig. 1. An occupied region of the robot A is equivalent to a spatial region defined by X-Z planes Pa1 and Pa2. An occupied region of the robot B is equivalent to a spatial region defined by X-Z planes Pb1 and Pb2, likewise. In such a manner, each of these planes (Pa1, Pa2, Pb1, Pb2) is defined by X-Z plane, so that these planes are parallel to each other. Although the following will be described later, if circumstances permit, the occupied region of the robot A may be defined as a left-side (Y-axis minus direction) region of the plane Pa1; on the other hand, the occupied region of the robot B is defined as a right-side (Y-axis plus direction) region of the plane Pb2.

As described above, the spatial region which a robot under a posture at the time occupies is set at every unit operation. In other words, a position (Y coordinate value) of X-Z plane defining the spatial region is thus determined. The operation of robots is controlled lest the spatial region determined thus and a spatial region determined for the other (adjacent) robot cross each other, namely lest the X-Z plane defining one spatial region cross over the X-Z plane defining the other spatial region. Thus, it is assured that no interference occur between robots.

Next, in case of defining spatial regions of the robots with the two X-Z planes, how to determine a

position (Y coordinate value) on each plane will be explained below with reference to the robot A shown in Fig. 1.

In the robot A having an orientation as shown in Fig. 1, the wrist Wa or the hand Ha is situated on the closest position to the adjacent robot B side or the maximum position in the Y-axis direction. As shown in Fig. 1, a sphere Cha covering the wrist Wa and the hand Ha is imaged now. One X-Z plane Pa1 is set to a position (Y coordinate value) such that the plane Pai contacts with the sphere Cha and receives it within the spatial region defined by the plane Pa1 (in Fig. 1. that position is shown as Ya (max)). If only the plane Pa1 is set in this manner, so far as the adjacent robot (the spatial region thereof) does not enter the spatial region of the robot A beyond the plane Pa1, it is ensured that no interference occurs between robots. In this case, the central position of the sphere Cha is determined by giving a specified offset amount to a wrist center position which is one of operating command positions to the robot. Further, a radius ra1 is determined on the basis of mechanism of the wrist Wa and the hand Ha. In such a case, if the position of the wrist Wa changes according to operation command, the position of the sphere Cha also changes. Therefore, the X-Z plan Pa1 defining the spatial region moves in parallel and in the Y-axis direction, and then the spatial region is changed.

In a state as shown in Fig. 1, the position at which hand Ha or the wrist Wa is situated has the maximum Y coordinate value in the robot A, as previously described. For this reason, the X-Z plane Pa1 is set on the basis of the position of the sphere Cha covering the wrist Wa and the hand Ha. However, if arms Aa1 and Aa2 are bent, and Y coordinate value of the elbow joint Ja becomes greater in the operation process, then Y coordinate value of the wrist Wa and the hand Ha becomes small. Therefore, there is the possibility that then Y coordinate value of the elbow joint Ja becomes greater than that of the wrist Wa and the hand Ha. In such a case, a sphere Cea covering the elbow joint Ja is assumed in order to set an appropriate spatial region. In the case where Y-axis coordinate value of the sphere Cea is greater than that of the Cha covering the wrist Wa and the hand Ha, one X-Z plane Pa1 is set to a position (Y coordinate value) such that the plane Pa1 is tangential to the sphere Cea and the sphere Cea is received in the spatial region defined by the plane Pa1. Further, the central position of the Cea covering the elbow joint Ja is determined according to the elbow joint position which is one of operation command positions to the robot, and a shape of the elbow joint. In this case, when the position of the sphere Cea changes as the elbow joint Ja is changed according to the operation command, the X-Z plane Pa1 defining the spatial region moves in parallel and in the Y-axis direction, thus the spatial region being shifted.

The above setting of the plane Pa1 has been explained on the assumption that either of Y coordinate values of the sphere Cha covering the wrist Wa and the hand Ha, and Y coordinate values of the sphere covering the elbow joint Ja is greater than Y coordinate value of the base Sa. However, when either of Y coordinate values of the sphere Cha covering the wrist Wa and the hand Ha, and the sphere covering the elbow joint Ja becomes smaller than Y coordinate value of the base Sa. it is necessary to consider the possibility that the adjacent robot B interferes with the base Sa of the robot A. In such a case, the base Sa is regarded as being a cylinder having the center extending from the center Oa of the base to the Z-axis direction, and one plane Pa1 is set to a position (Y coordinate value) such that it is tangential to the cylinder, and the cylinder is received in the spatial region defined by the plane Pa1. The center of cylinder representing the base Sa is determined on the basis of the mounting position of the robot. Further, the radius α of cylinder is determined on the basis of a shape of the base. As a matter of course, the position of this cylinder is always constant regardless of an operation of the robot.

Summarizing the above description, in the case of determining the setting position Ya(max) of one X-Z plane Pa1 defining the spatial region, first, respective segments on the Y-axis of the sphere Cha covering the wrist Wa and the hand Ha, the sphere Cea covering the elbow joint Ja and the cylinder representing the base Sa are compared, and the sphere or the cylinder, which has the greatest Y coordinate value, is specified from them. Then, the plane Pa1 is set to Y coordinate value such that the plane Pa1 abuts on the specified sphere or cylinder, and the sphere and the cylinder are received in the spatial region defined by the plane Pa1.

On the other hand, in the case of determining the other X-Z plane Pa2 defining the spatial region, if it is previously found that any of segments on the Y-axis of the sphere covering the wrist Wa and the hand Ha and the sphere Cea covering the elbow joint Ja is not smaller than the segment on the Y-axis of the cylinder representing the base Sa, the plane Pa2 is set to Y coordinate value Ya(min) such that it is tangential to the cylinder representing the base Sa, and the cylinder is received in the spatial region.

If a third robot is not mounted on the Y-axis minus direction side (on the left of the robot A in Fig. 1), it is not necessary to consider that other robots enter the occupied spatial region of the

robot A beyond the X-Z plane Pa2. Therefore, the setting of the position of the plane Pa2 causes little problem. Further, the plane Pa2 is not set in such a case, and the spatial region may be regarded as a region in the Y-axis minus direction from the plane Pa1. But, if a third robot is mounted on the left of the robot A, there is a need of considering interference with the third robot, so that it is a significant matter where the aforesaid plane Pa2 should be set. In this case, the spatial region must be defined by two X-Z planes (Pa1, Pa2). In accordance with an operation of the robot A, it would be necessary to determine the plane Pa2 in the same manner that an X-Z plane Pb2 is set in a robot B, which will be explained below.

Next, the setting of a spatial region for a robot B will be described below. This setting is basically performed with the same procedures as in the case where the spatial region for the robot A is set. First, a sphere Chb (radius rb1) covering a wrist Wb and a hand Hb and a sphere Ceb (radius rb2) covering an elbow joint Jb are assumed, respectively, and a cylinder (radius β) representing a base Sb is further assumed. However, in the case of the robot B, the aforesaid robot A exists in the Y-axis minus direction or the left side of the robot B. In view of such a positional relation, first, respective segments on the Y-axis of the sphere Chb covering the wrist Wb and the hand Hb, the sphere Ceb covering the elbow joint Jb and the cylinder representing the base Sb, are compared, and the sphere or the cylinder, which has the smallest Y coordinate value, is specified from among them. Then, one X-Z plane Pb2 is set to Y coordinate value Yb (min) such that the plane Pb2 is tangential to the specified sphere or cylinder, and the sphere and the cylinder are received in the spatial region defined by the plane Pb2. The other X-Z plane Pb1 is set to Y coordinate value Yb(max) such that the plane Pb1 abuts on the cylinder representing the base Sb, and the cylinder is received in the spatial region defined by the plane Pb1. Further, in the same manner as described in the robot A, the plane Pb1 is not specifically set, and the spatial region occupied by the robot B may be defined as a region in Y-axis plus direction from the X-Z plane Pb2.

When the spatial regions of two robot A and B thus set do not cross each other, it is ensured that no interference occurs between these robots, as previously explained. Therefore, these robots are controlled so that the spatial regions of these robots do not cross each other.

Assuming that the robots A and B have the origins Oa and Ob, and X-Y-Z coordinate system having X-, Y-, Z-axis direction in common, respectively, the following equation is established when the spatial regions of two robots do not cross each other.

$$Ya\ (max) - Yb\ (min) < d \qquad (1)$$

(Where, d is the distance between the origins Oa and Ob)

Figs. 2 and 3 are configuration diagrams of a control system in the case where a plurality of robots are simultaneously operated to execute a task, and are the same configuration as carried out in the prior art. Fig. 2 shows a configuration in the case where the plurality of robots are controlled by means of a single robot controller C1. In Fig. 2, two robots A and B are connected to the controller, but other robots may be further connected thereto. On the other hand, Fig. 3 shows a configuration in the case where a robot controller C2 for the robot A and a robot controller C3 for the robot B are connected by communication means. Further, in Fig. 3, the robot controllers C2 and C3 are connected to the robots A and B, respectively, but two or more robots may be connected to each controller.

Fig. 4 is a block diagram showing a configuration of a robot controller. This robot controller has the same configuration as a conventional controller, and has been already known. To a processor (CPU) 10 are connected, through a bus 15, a ROM 11 storing system programs, a RAM 12 storing teaching programs for each robot, various setting values, parameters or the like, a servo module 13 for driving a servo mechanism (servo motor) of each robot, and an I/O module 14 for inputting and outputting signals from various sensors of each robot or an actuator, through a bus 15. Incidentally, a function of each of the above elements is already known, so that its detailed description is omitted here.

Referring now to a flowchart shown in fig. 5, an operation according to the present embodiment will be described below. The present embodiment employs the control system shown in Fig. 3. Each operation of the robots A and B is commanded on the basis of individual X-Y-Z coordinate systems having X-, Y-, Z-axis direction in common. The following is mainly the explanation relating to an operating process of the robot A. Further, Fig. 5 is a flowchart of the operating process on the basis of operating programs which are already taught to the robot A shown in fig. 1.

First, prior to the operating process, various parameters concerning the robot A are stored in the robot controller C2. More specifically, the following data are set: an offset amount to the central position of the wrist (operation command position to the robot) for determining the central position (hereinafter referred to as hand representative position) of the sphere Cha covering the wrist Wa and

the hand Ha of the robot A; a radius ra1 of the sphere Cha; a radius ra2 of the sphere Cea covering the elbow joint Ja; a radius α of the section of the cylinder representing the base Sa; distance d between two robots adjacent to each other.

When a operation command for the robot A is inputted, the processor 10 of the robot controller C2 first estimates a current position (central position of the wrist) of the robot A and also estimates a position of the elbow joint Ja during this process. Then, a hand representative position is calculated on the basis of the estimated current position (central position of the wrist) and a specified offset amount to a hand representative position (Step S1). In this case, data required for the hand representative position and the elbow joint position is only Y coordinate values Yha and Yea.

Next, three values, namely the radius α of the base preset to the robot A, a value (Yha + ra1) to which the radius ra1 of the sphere Cha and the hand representative position Yha are added, and a value (Yea + ra2) to which the radius ra2 of the Cea and the position Yea of the elbow joint Ja are added, are compared, and the greatest value of these three values is stored in a register as Y coordinate value Ya(max) of the X-Z plane Pa1 for defining an occupied spatial region of the robot A (Step S2). In this case, it is assumed that the robot B do not go beyond the other X-Z plane Pa2 defining the occupied spatial region of the robot A, so that it is not necessary to set Y coordinate value of the plane Pa2. In other words, the occupied spatial region of the robot A is set as a region having Y coordinate value smaller than the plane Pa1. The maximum value Ya(max) stored in this register is transmitted to the robot controller C of the robot B, and is stored in memory means of the controller. In this case, during operating process, a judgement is made whether or not the X-Z plane Pb2 defining the spatial region of the robot B is beyond the plane Pa1 which is set to the aforesaid Ya(max) of the robot A. If it is beyond the plane, the operation of the robot B is interrupted.

Subsequently, one block (a line in programs, or unit operation command) is read according to the taught operation programs (Step S3), and it is judged whether or not the aforesaid command is an operation command (Step S4). Unless it is the operation command, then it is judged whether a termination command is commanded in the programs, or inputted by an operator (Step S11). If the termination command is not issued, other commanded processings are executed (Step S12), and the sequence returns to Step S3. Further, if it is determined, at the next step S4, that the read command is an operation command, the hand representative position Yha' and the elbow joint position Yea' are estimated on the basis of the robot position according to the operation command, in the same manner as estimated at Step S1 (Step S5) Furthermore, the maximum value Ya(max)' of the spatial region when the operation command is executed is estimated, in the same manner as estimated at Step S2 (Step S6).

It is judged whether the following equation (2) is established by using the aforesaid equation (1) on the basis of the maximum value Ya(max)' of the spatial region thus estimated, and the minimum value Yb(min)' of the current spatial region of the robot B, which is transmitted from the controller C3 of the robot B and stored in memory means of the controller C2 of the robot A.

$$Ya(max)' - Yb(min)' < d \qquad (2)$$

Then, it is determined whether or not the robot A exists in a safe region where it does not interfere with the robot R, thus an interference check being executed (Step S7).

In the case where the above equation (2) is not established, and it is not ensured that no interference occurs, due to the cross of the spatial regions of the adjacent robots, the aforesaid processings of Step S7 are repeatedly executed. In the meantime, the robot A is temporarily stopped operating, and is kept in a waiting state. On the other hand, the robot B is operated according to the operation command, and accordingly its spatial region is shifted depending on the operation of the robot. The minimum value Yb(min)' of the spatial region is transmitted to the robot controller C2 of the robot A, and the value of Yb(min)' in the above equation (2) is modified in Step S7 so that the equation (2) can be established. If the conditions described above are arranged, first, the greater value of either maximum value Ya(max) or Ya(max)' before and after one operation is executed is selected as the maximum value Ya(max) of the spatial region, and is stored in the register (Step S8), thus the operation corresponding to this command being executed (Step S9).

The maximum value Ya(max) of the spatial region secured in Step S8 is transmitted to the robot controller C3 of the robot B, and is stored in memory means thereof. Then, during the operating process, it is judged whether or not the X-Z plane Pb2 defining the spatial region of the robot B is beyond the plane Pa1 which is set to the above maximum value Ya(max) of the robot A. If it is beyond the plane Pa1, the robot B is stopped operating. In this case, the processing of Step S8 is executed, and the processing result is supplied to the robot B side. This means that the spatial region of the robot A is modified when the robot A moves from a certain point to the next point. However, during the operating process, if only any of

the spatial regions which is greater than the other is selected and maintained, then it is safely ensured that interference with the robot A will not occur, based on the fact that the spatial region thus maintained of the robot B will not enter the secured spatial region of the robot A.

Subsequently, when the execution of the operation at Step S9 is complete, the position Ya(max)' of the X-Z plane Pa1 defining the occupied spatial region of the robot after the operation is complete is stored in the register (Step S10). Then, the sequence returns to Step S3, and processings for the next block is executed there.

In the flowchart shown in Fig. 5, only processing concerning the robot A is described therein. Further, the processing concerning the robot B is also executed in the same manner as the robot A. However, in Step S2, three values, namely the value ($-\beta$) which is obtained by multiplying the base radius β preset for the robot B by minus 1, the value (Yhb + rb1) which is obtained by adding the radius rb1 of the sphere Chb to the hand representative position Yhb, and the value (Yeb + rb2) which is obtained by adding the radius rb2 of the sphere Ceb to the position Yeb of the elbow joint Jb, are compared, and the smallest value of these values is stored in the register as the minimum value of the spatial region, or Y coordinate value Yb(min) of the X-Z plane Pb1 for defining a spatial region in which the robot b is received. Likewise, in Step S6, the minimum value Yb(min)' of the spatial region when the robot B is operated according to the operating command in the same manner as step S1 is obtained. In Step S8, the smallest value of the two data, namely the minimum values Yb(min) and Yb(min)' before and after one operation of the robot is executed, is stored in the register as the minimum value Yb(min) of the spatial region, and the occupied spatial region where the robot is operating is ensured.

The aforesaid operation has been explained in terms of the execution according to programs. In the case of teaching the operation to the robots, the same processing as described above is executed. In other words, there is a case where the operation is taught to one robot, while it is taught to the other robot, or the teaching operation is executed during the operation of the other robot. This teaching operation is the same process as shown in the flowchart of Fig. 5, except that Steps S3 and S4 of the flowchart shown in Fig. 5 are replaced as a process for making a judgement whether or not teaching commands are inputted, and Step S11 is replaced as a process for making a judgement whether or not the teaching termination command is inputted.

According to the above embodiment, the interference check is performed with the operation command unit. However, the interference check may be performed for each interpolation point after interpolating calculation is executed. In other words, if it is determined, at Step S4 of Fig. 5, that the inputted command is an operation command, each interpolation point is estimated by executing interpolating calculation on the basis of the aforesaid command, and the hand representative position and the elbow joint position (Yha', Yea'; Yhb', Yeb') corresponding to each interpolation point are determined. Then, processings of Steps S6 through S10 are repeatedly executed from the initial interpolation point, and when the final operation command is executed, a process for returning to Step S3 may be executed.

The above embodiment is directed to a control for preventing interference between two robots from occurring, as shown in Fig. 1. However, even if many robots are further mounted, it is possible to execute a control for preventing interference between robots from occurring, likewise. For example, in Fig. 1, if a third robot is mounted on the left side of the robot A, the interference check between the robots A and C is performed in the same manner. In this case, the relation between the robots A and B shown in Fig. 1 is merely replaced as the relation between the robots C and A. However, in the robot A which is situated on the center position, three values, namely the value ($-\alpha$) which is obtained by multiplying the base radius α preset for the robot A by minus 1, the value (Yha + ra1) which is obtained by adding the radius ra1 of the sphere Cha to the hand representative position Yha, and the value (Yea + ra2) which is obtained by adding the radius ra2 of the sphere Cea to the position Yea of the elbow joint Ja, are further compared in Step S2, and the smallest value of these is set as the minimum value of the spatial region (Y coordinate value Ya(min)). Then, the spatial region which the robot A occupies is defined by two X-Z planes Pa1 and Pa2, which are set to the minimum value Ya(min) and the aforesaid maximum value Ya(max), respectively. Further, if it is previously found that respective Y coordinate values of the hand, wrist, and elbow joint of the robot A do not exceed Y coordinate value of the base Sa to become smaller, Ya(min) is determined as: Ya(min) = $-\alpha$. Furthermore, in Step S6, the minimum value Ya(min)' of the spatial region when the operation command is executed, is estimated at the same time that the maximum value Ya(max)' is estimated. Likewise, in Step S8, the smallest value of two data, namely the minimum values Ya(min) and Ya(min)' of the spatial region before and after one operation is executed, is selected as the minimum value Ya(min) of the spatial region. Then, the minimum value Ya(min) is stored in the register together with the maximum value Ya(max) of the spatial region, thereby ensur-

ing not only the maximum value but also the minimum value of the occupied spatial region of the robot A.

Further, in the case where a robot D is mounted on the right side of the robot B, the relation between the robots A and B shown in Fig. 1 is merely replaced as the relation between the robots B and D.

The above embodiment uses positions of the elbow joints Ja and Jb of the robots as a factor for determining the spatial region where the robots are operated. However, in the case of a vertical multi-joint robot, it is seldom that the elbow joints Ja and Jb bend in the Z-axis direction to be positioned further from the origins Oa and Ob on the Y-axis than from its hand position. For this reason, in the case where operation program such that the elbow joints Ja and Jb bend in the Z-axis direction and are positioned further from the origins Oa and Ob on the Y-axis than from its hand position is not taught in a robot teaching program, as described above, no positions of the elbow joints Ja and Jb robot teaching programs may be used as a factor for determining the spatial region. On the contrary. in the case of a robot such that the plurality of elbow joints of a robot may be positioned further from the origins Oa and Ob on the Y-axis than from its hand position, it is necessary to consider each of all elbow joints of the robot in order to determine the spatial region of the robot.

Further, in the above embodiment, each robot has a common coordinate system in which the direction connecting between the origins Oa and Ob is regarded as a Y-axis direction, a mounting plane of the robot is regarded as a X-Y plane, and a spatial region, where each robot is received, is defined by one or two X-Z planes, and the moving direction of the robot is regarded as Y-axis direction. But, there is no need of limiting the plane of defining the spatial region to the X-Z plane, and limiting the moving direction to Y-axis direction. In short, the spatial region of each robot is defined by the planes which move in the specified direction, and are parallel to each other throughout all concerned robots. Thus, in a normal operation having no interference, it is necessary that only a state in which the spatial region of each robot does not cross can be reasonably obtained. As described above, the occupied spatial region of the robot is defined by planes parallel to each other. However, it is not necessary that all of these robots be mounted on the identical plane.

As seen from the above explanation, according to the present invention, before the robot moves actually, the spatial region of the robot required for its movement is defined by the planes moving in parallel, so that a position (orientation) and one operation of the robot can be ensured. In the case where when one robot executes one operation, one robot crosses the occupied spatial region of the other robot, it is determined that there is the possibility of interference (In other words, it is not ensured that no interference occurs) and the operation of the robot is stopped. In the meantime, the other robot is operating; as a consequence, one robot waits until both robots become a state in which their spatial regions do not cross each other. Then, when both robots reach a state in which their spatial regions do not cross each other, one robot starts operating again. Therefore, according to the present invention, there is no need of complicated computation for predicting interference regions, and of presetting the timing of communication between the robots, so that operation programs can be freely taught and executed relative to each robot. Thus, it is possible to reduce the number of processes for operating the robots.

Claims

1. A multiple-robot control method, comprising the steps of:

   defining a spatial region for keeping a region necessary for the operation at every unit operation command, for each of a plurality of robots which are mounted close to each other and may be commanded so as to be operated at the same time;

   finding whether said spatial region defined for one robot crosses a spatial region defined likewise for other robot; and

   judging whether it is ensured that no interference between robots will occur.

2. A multiple-robot control method according to claim 1, wherein said method further comprises the steps of;

   finding that the spatial region defined and kept for one robot crosses the spatial region defined and kept for the other robot, and controlling so that said one robot is stopped operating according to the detected result, and is kept in a waiting state until the spatial region of the other robot shifts depending on an operation of the other robot and the spatial regions of both robots do not any longer cross each other.

3. A multiple-robot control method according to claim 1, wherein the occupied spatial region of said each robot is defined by one or two planes which are parallel to each other and horizontally moves in a specified direction for all of robots.

4. A multiple-robot control method according to claim 3, wherein said plane for defining the spatial region of each robot is set to a position such that the plane is tangential to the sphere or cylinder obtained by assuming at least one of a sphere covering a wrist and hand of the robot, a sphere covering an elbow joint of the robot, and a cylinder representing a base of the robot, and receives it within the region defined by the plane.

5. A multiple-robot control method according to claim 3, wherein said plane for defining the spatial region of each robot is set to a position such that the plane is tangential to the sphere or cylinder detected as being positioned the furthest place from the robot base in the moving direction of the planes, of the at least two of spheres or cylinder which are assumed from among a sphere covering an elbow joint of the robot, and a cylinder representing a base of the robot, and receives it within the region defined by the plane.

6. A multiple-robot control method according to claim 5, wherein the central position of said assumed sphere covering the wrist and the hand of the robot is set to a position where a predetermined offset value is added to the wrist center position which is one of operating command positions, and the radius of the sphere is determined on the basis of the structure of the wrist and the hand.

7. A multiple-robot control method according to claim 1, wherein said unit operation command for defining the spatial region of each robot is equivalent to one block of operating programs which is taught to the robot.

8. A multiple-robot control method according to claim 1, wherein said unit operation command for defining the spatial region of each robot is equivalent to one unit on which the operating command taught to the robot is interpolated.

9. A multiple-robot control method according to claim 1, wherein the spatial region closest to the adjacent robot of a spatial region newly defined when the unit operation of each robot is started, and a spatial region defined just before the operation, is maintained as a spatial region for current operation until the next unit operation is started, and data of the maintained spatial region is transmitted to the adjacent robot side, and it is found whether or not the spatial region of the robot receiving the data crosses said spatial region of the transmitting-side robot, thus determining whether it is ensure that both robots have no interference with each other.

10. A multiple-robot control method according to claim 9, wherein if it is found that the spatial region of the receiving-side robot crosses said spatial region of said transmitting-side robot, the receiving-side robot is stopped operating, and is controlled so as to be kept in a waiting state until the spatial region of the receiving-side robot is moved depending on the operation of the transmitting-side robot, and the spatial regions of both robots do not cross each other.

11. A multiple-robot control method according to any one of claims 1 through 5, and 7 through 10, wherein at least one of said multiple robots is of a vertical multi-joint type robot.

FIG. 1

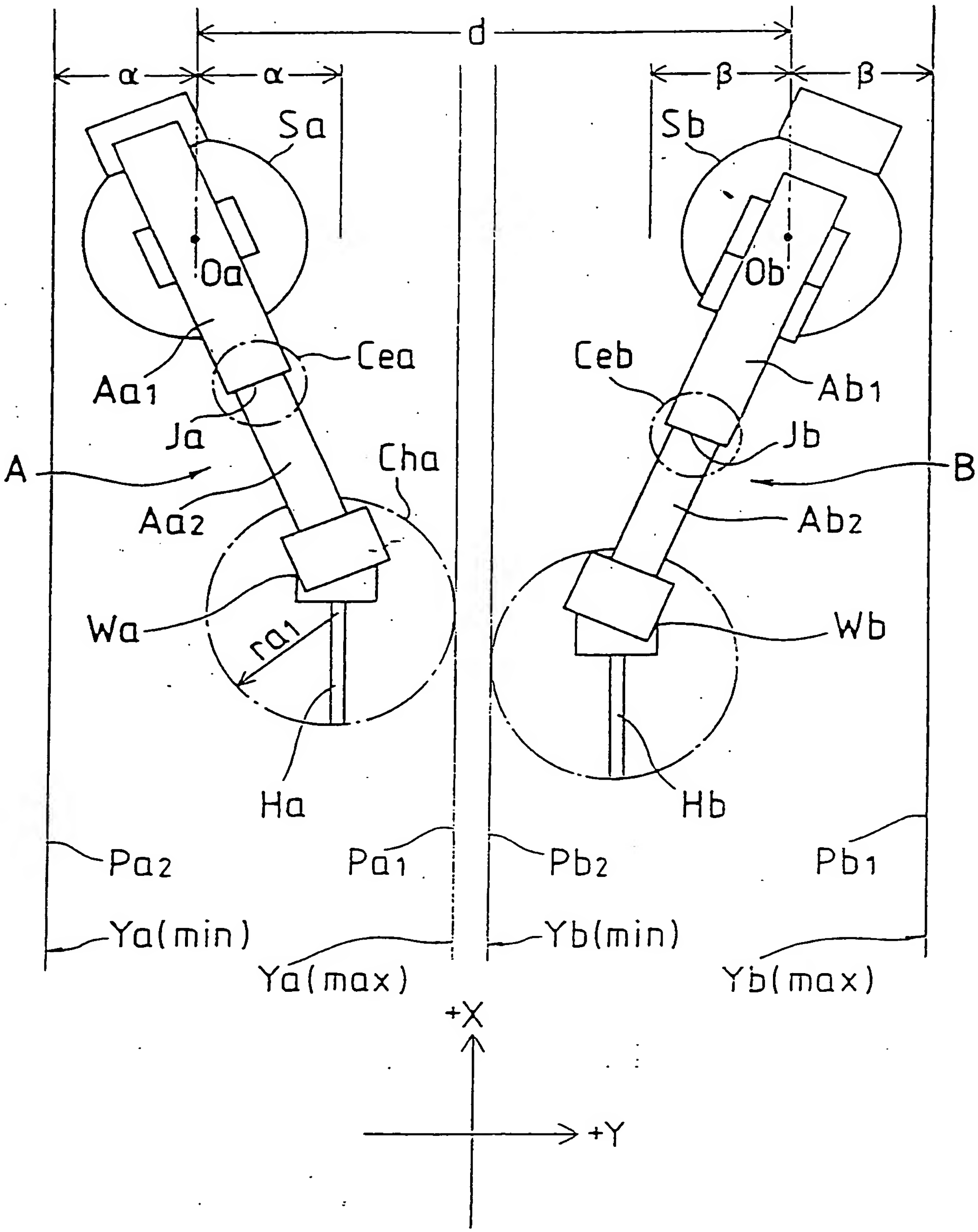

d
α
α
β
β
Sa
Sb
Oa
Ob
Cea
Ceb
Aa1
Ab1
Ja
Jb
A
B
Cha
Aa2
Ab2
Wa
Wb
ra1
Ha
Hb
Pa2
Pa1
Pb2
Pb1
Ya(min)
Ya(max)
Yb(min)
Yb(max)
+X
+Y

Fig. 2

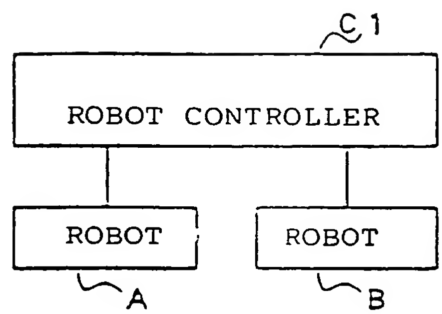


Fig. 3

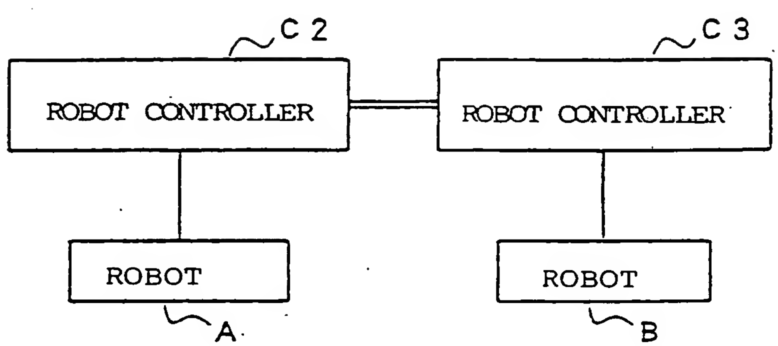


Fig. 4

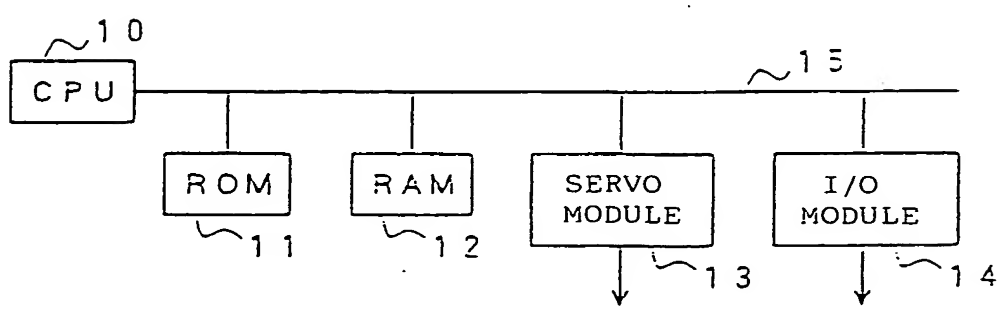
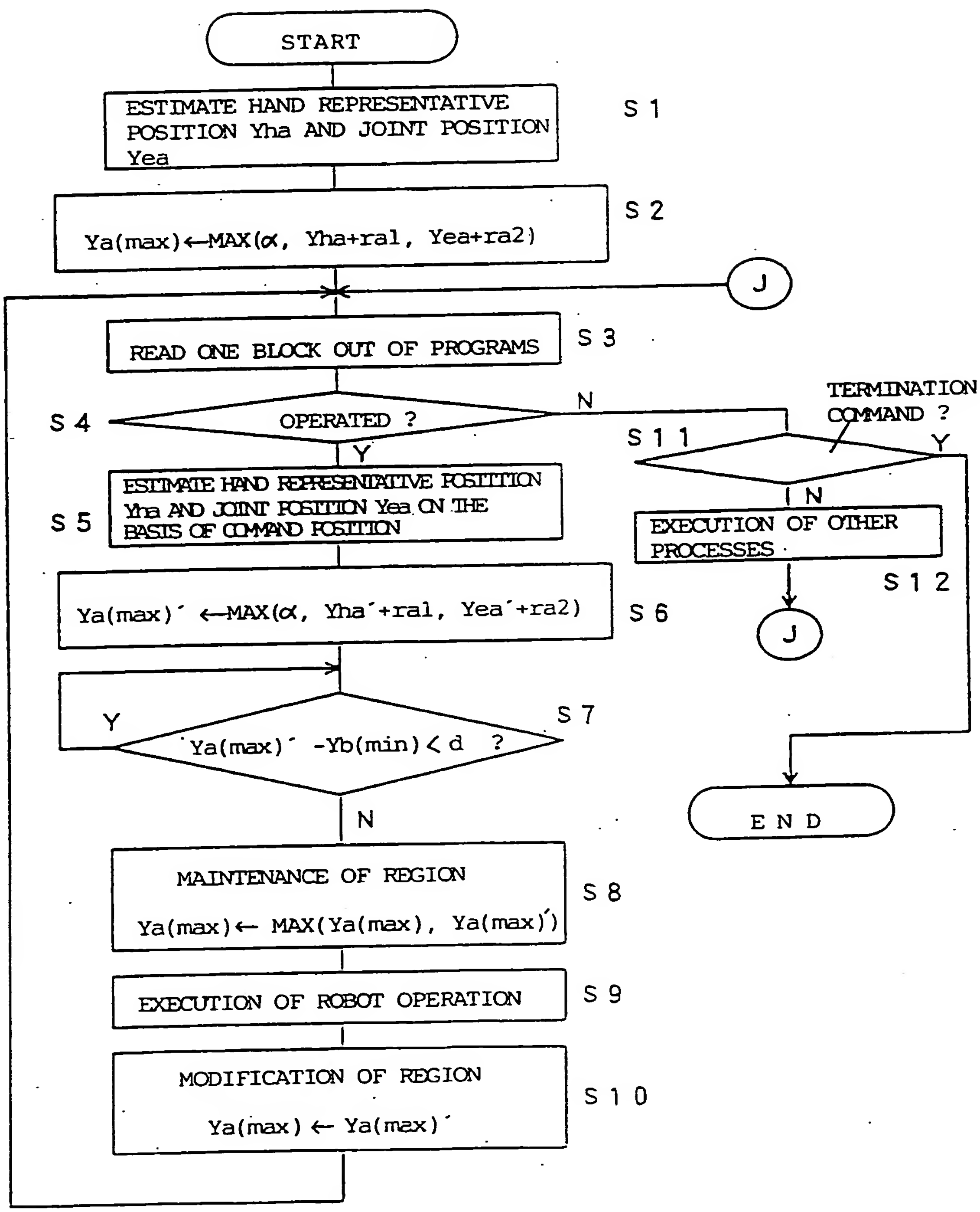


Fig. 5


START
ESTIMATE HAND REPRESENTATIVE POSITION Yha AND JOINT POSITION Yea
S 1
Ya(max)←MAX(α, Yha+ra1, Yea+ra2)
S 2
J
READ ONE BLOCK OUT OF PROGRAMS
S 3
S 4
OPERATED ?
N
Y
TERMINATION COMMAND ?
S 1 1
Y
N
ESTIMATE HAND REPRESENTATIVE POSITION Yha AND JOINT POSITION Yea ON THE BASIS OF COMMAND POSITION
S 5
EXECUTION OF OTHER PROCESSES
S 1 2
Ya(max)´ ←MAX(α, Yha´+ra1, Yea´+ra2)
S 6
J
Y
Ya(max)´ -Yb(min)< d ?
S 7
END
N
MAINTENANCE OF REGION
Ya(max)← MAX(Ya(max), Ya(max)´)
S 8
EXECUTION OF ROBOT OPERATION
S 9
MODIFICATION OF REGION
Ya(max) ← Ya(max)´
S 1 0

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP93/00055

A. CLASSIFICATION OF SUBJECT MATTER

Int. Cl^5 B25J19/06

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

Int. Cl^5 B25J13/00, 19/06

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Jitsuyo Shinan Koho	1926 - 1993
Kokai Jitsuyo Shinan Koho	1971 - 1993

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
	JP, A, 59-205601 (Hitachi, Ltd., Hitachi Keiyo Engineering K.K.), November 21, 1984 (21. 11. 84), (Family: none)	
X		1-8, 7, 8
Y		4, 9-11
A		5, 6
Y	JP, A, 63-289606 (Toshiba Corp.), November 28, 1988 (28. 11. 88), (Family: none)	4, 11
Y	JP, B2, 60-5968 (Shin Meiwa Industry Co., Ltd.), February 15, 1985 (15. 02. 85), (Family: none)	9-11

[X] Further documents are listed in the continuation of Box C. [ ] See patent family annex.

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"P" document published prior to the international filing date but later than the priority date claimed

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"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
April 2, 1993 (02. 04. 93)	April 27, 1993 (27. 04. 93)
Name and mailing address of the ISA/ Japanese Patent Office Facsimile No.	Authorized officer Telephone No.